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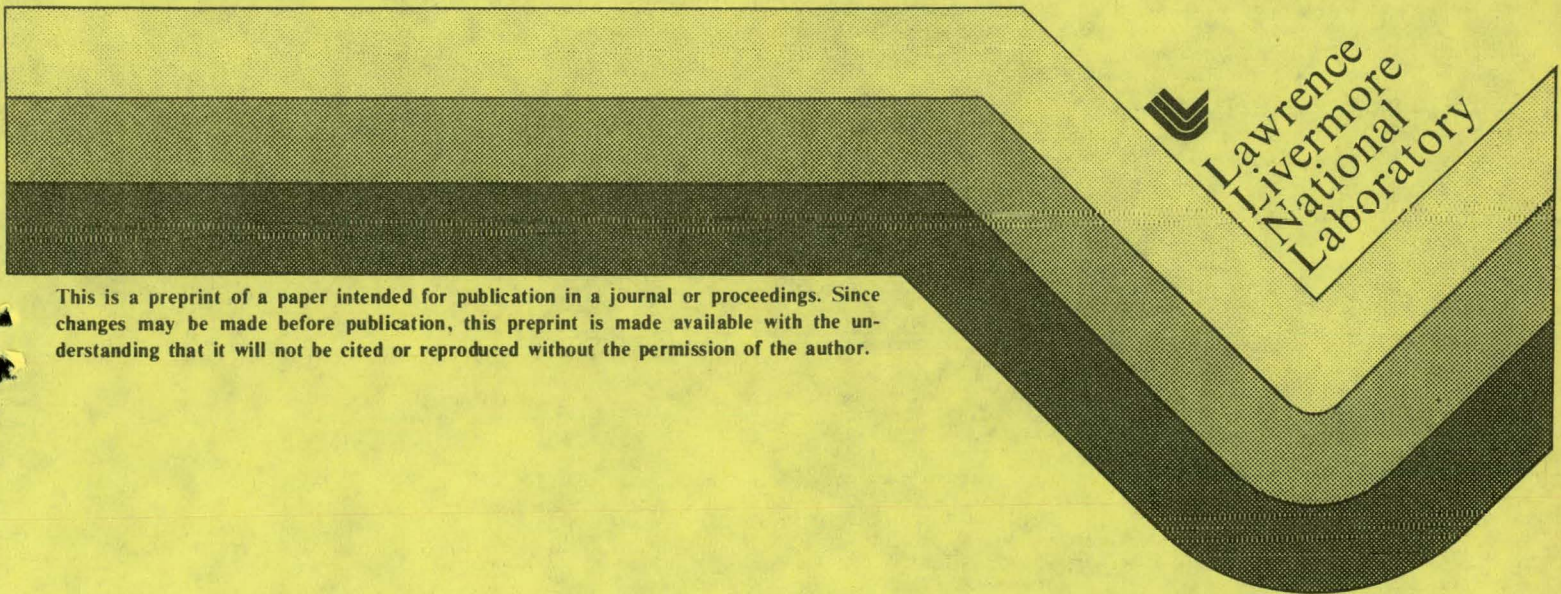
**MASTER**

RADIOLOGICAL DESIGN CRITERIA FOR  
FUSION-POWER TEST FACILITIES

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RADIOLOGICAL DESIGN CRITERIA FOR  
FUSION-POWER TEST FACILITIES\*

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ABSTRACT

The quest for fusion power and understanding of plasma physics has resulted in planning, design and construction of several major fusion power test facilities, based largely on magnetic and inertial confinement concepts. We have considered radiological design aspects of the Joint European Torus (JET), Livermore Mirror and Inertial Fusion projects, and Princeton Tokamak. Our analyses on radiological design criteria cover acceptable exposure levels at the site boundary, man-rem doses for plant personnel and population at large, based upon experience gained for the fission reactors, and on considerations of cost-benefit analyses.

1. INTRODUCTION

Nuclear fusion offers the possibility of an inexhaustible energy source which can use universally available deuterium contained in the surface and ocean waters and have minimal adverse environmental impacts. Achieving fusion poses extremely difficult physics and engineering challenges which are currently being addressed cooperatively worldwide. Fusion offers substantial environmental and safety advantages over fission, and to fully realize these advantages and avoid delays and frustrations later on it is extremely important that we incorporate safety into design at the puberty stage. The major hazard associated with fusion systems using deuterium-tritium fuel cycle is potential personnel exposure to activated products and tritium. The radiological design objective should be to limit personnel exposures from

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these sources to levels that would be acceptable to the public at large.

## 2. RADIOLOGICAL DOSE CRITERIA

Although some plasma physics and engineering experiments can be done using hydrogen or deuterium, advanced experiments and first generation fusion reactors are likely to use the deuterium-tritium fuel cycle. The tritium fuel itself is radioactive and can pose internal exposure problems. The D-T fusion reaction will result in the production of 14 MeV neutrons. Interaction of these neutrons with the first wall, vacuum vessel and various reactor components will result in considerable residual radioactivity. This can pose exposure problems when doing maintenance and repair work.

Fusion technology, however, will eliminate current major public safety concerns regarding the operation of fission reactors; namely, risks from accidental release of large amounts of radioactivity after meltdown of fuel, possibility of sabotage, safety of transportation, storage and disposal of fission products and transuranic wastes, and possible diversion of reactor fuel to military use.

Thus, the common radiological ground that fusion and fission shares is exposure from activated products and tritium. Activated products are the major sources of employee exposures at commercial nuclear power plants. The exposure history in the United States nuclear program shows that maintenance and repair work account for about 70% of employee doses, with the average dose per plant being about 500 man-rem/yr (1.2 man-rem/MW(e)yr).<sup>(1)</sup> The average dose per exposed individual is about 0.8 rem/yr. During the past 5 years the doses have increased to 1.8 man-rem/MW(e)-yr.<sup>(2)</sup> In contrast, the employees in the United Kingdom at the gas-cooled nuclear reactor program have experienced on the average only 0.25 rem/yr doses.<sup>(3)</sup> The employee doses, without refueling operations, at a 1200 MW(e) power plant built by Kraftwerk Union are only 0.05 man-rem/MW(e)-yr.<sup>(4)</sup> Similarly, doses experienced by employees in the Swedish BWRs have been very low, 0.06 man-rem/MW(e)-yr.<sup>(5)</sup> The majority of occupational exposures at these plants occurred when the employees were doing maintenance and repair work on reactor components that were contaminated with neutron-induced residual radioactivity. Although the doses received by employees at these plants are low, there is an increasing pressure to further lower these doses to levels that are as low as reasonably achievable, subject to economic and social considerations. The philosophy on maintaining exposures as low as reasonably achievable is being legislated worldwide for every operation involving radiation. The fusion facilities

hence are expected to be designed, operated and decommissioned in accordance with the as low as reasonably achievable criterion as well.

Based on the prevailing occupational exposure philosophy, and exposures currently being experienced by the fission industry, the primary radiological safety objective of fusion facilities would be to limit individual and collective doses to their lowest, taking various factors into account, such as the basic limits, reduction based on cost-benefit analyses, selection of materials for low activation, use of remote handling techniques for maintenance and repair work, modularizing reactor components for easy removal to hot cell facilities, proper containment of tritium to minimize leaks under normal and postulated abnormal conditions, etc.

Design limits should be as realistic as possible. There is no need to be overly conservative if the doses are well below the basic limits and are well within the natural background fluctuation levels. The following exposure limits should be used as the starting point for designing and operating fusion facilities:

Maximum individual doses on site	$\leq 5$ rem/yr
Collective dose per plant	$\leq 0.05$ man-rem/MW(e)-yr
Collective dose per experimental facility	$\leq 10$ man-rem/yr
Average occupational dose for radiation worker	0.25 rem/yr
Off-site individual dose	0.005 rem/yr
Collective dose off-site (low population zone)	30 man-rem/yr

The collective dose 10 man-rem/yr per experimental fusion facility is based on exposure experience gained during the last two years at the Lawrence Livermore Rotating Target Neutron Source facility, which generated 14 MeV neutron fluences comparable to those planned daily for the mirror machines, Nova, Torus and Tokamak devices.

The collective dose for plant employees as indicated above should be limited to about 0.05 man-rem/yr-MW(e). For a 500 MW(e) fusion plant, the upper design dose limit becomes 25 man-rem/yr.

### 3. COST/BENEFIT ANALYSIS

Further reduction on the above dose rates should be based on cost/benefit analyses. The monetary expenditure to reduce a unit dose is a matter of personal judgement, and the following is, in our opinion, a reasonable expenditure per

cutting dose below the design or basic limits. These values are very similar to those currently recommended to optimize public protection by the United Kingdom National Radiological Protection Board. (6)

<u>Individual dose range (rem)</u>	<u>Cost per further (\$/rem)</u>
0 - 0.005	--
0.005 - 0.05	>200
0.05 - 0.5	>1000
0.5 - 5	>2000

#### 4. SUMMARY

The radiological dose design limits suggested in this paper for future fusion installations are based upon the lowest doses currently being experienced at some fission power installations. There will be a continuing emphasis to keep radiation doses in the nuclear industry as low as is reasonably achievable below the basic limits. The as low as is reasonably achievable doses are likely to mean 0.25 rem/yr for radiation workers and 0.06 man-rem/MW(e)-yr for nuclear installations. It would seem reasonable then to use these dose limits for design objectives of fusion facilities.

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